Artículo de investigación

Investigation of the Causes of Petrochemical Concrete Structures Destruction In Mahshahr and Proposed Solutions

Investigación de las causas de la destrucción de estructuras de hormigón petroquímico en Mahshahr y propuestas de solución

Investigação das causas da destruição de estruturas petroquímicas de concreto em Mahshahr e soluções propostas

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Abstract

Today, most civil structures are built of concrete, which's use is increasing daily. Due to ignoring the principles of constructuion (for the durability of the concrete), corrosion causes substantial costs to the structures after a small period of operation that in some cases rebuilding the structure is even more difficient rather than renovating it. This issue is even more critical about the structure exposed to sea water and the low service life in the southern coastal structures has confirmed so. Also, with huge resources of gas and oil being discovered as well as the construction of large petrochemical plants in the Persian Gulf have led to the need for major construction and development projects in the area. Hot and humid climate and minerals in the region are showing signs of deterioration, including numerous cracks, corrosion, efflorescence and welting the concrete. Reinforced concrete structures in the south of the country are exposed to chemical or electrochemical damage. The most important corrosion factor is due to air carbonation phenomenon (occurs as a result of carbon dioxide in the air) and chloride penetration (which passes through the concrete and reaches the reinforcement). The effects of corrosion and cracking and collapse of concrete and concrete sulfate decrease the beneficial life of the structure significantly. This type of damage is greater in the tide region because due to wetting and drying,

Resumen

En la actualidad, la mayoría de las estructuras civiles están construidas de hormigón, cuyo uso aumenta a diario. Debido a ignorar los principios de construcción (para la durabilidad del concreto), la corrosión causa costos sustanciales a las estructuras después de un pequeño período de operación que en algunos casos reconstruye la estructura es aún más difícil en lugar de renovarla. Este problema es aún más crítico sobre la estructura expuesta al agua de mar y la baja vida útil en las estructuras costeras del sur lo ha confirmado. Además, con los enormes recursos de gas y petróleo que se están descubriendo, así como la construcción de grandes plantas petroquímicas en el Golfo Pérsico han llevado a la necesidad de grandes proyectos de construcción y desarrollo en el área. El clima y los minerales cálidos y húmedos en la región muestran signos de deterioro, que incluyen numerosas grietas, corrosión, eflorescencia y rotura del hormigón. Las estructuras de hormigón armado en el sur del país están expuestas a daños químicos o electroquímicos. El factor de corrosión más importante se debe al fenómeno de la carbonatación del aire (que ocurre como resultado del dióxido de carbono en el aire) y la penetración del cloruro (que pasa a través del hormigón y llega al refuerzo). Los efectos de la corrosión, el agrietamiento y el colapso del

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chloride penetration influx into concrete is intensified and as a result the corrosion rate increases. In order to reduce the damage of reinforced concrete structures different methods are used and most important is improving the quality of concrete. In this study the prevention cases of reinforcement corrosion have been investigated and the type of cement and its additives such as silica and penitron were oxamined. The results indicate that the coating material consisting of penitron penitron increases cylinder compressive strength. But the main benefit of penitron is preventing the concrete's penetration. The best materials were selected by performing experiments and accordingly to the weather of Mahshahr, Samples of reinforced concrete structures with water-cement ratio of (w / c= 4% , w / c = 34%) and the lubricant of 6%- 2% range were built with a fixed slump, and taken under pressure tests. The results of the corrosion tests showed that he use of cement containing 10% silica with 34% water- cement ratio, armature FRP and penitron materials are the best technical and economic proposal in order to reduce corrosion in Mahshahr.

Keywords: concrete, water-cement ratio, cracks, corrosion, efflorescence.

concreto y del sulfato de concreto disminuyen significativamente la vida útil de la estructura. Este tipo de daño es mayor en la región de la marea porque debido a la humedad y el secado, se intensifica la afluencia de penetración de cloruro en el concreto y como resultado la tasa de corrosión aumenta. Para reducir el daño de las estructuras de hormigón armado se utilizan diferentes métodos y lo más importante es mejorar la calidad del hormigón. En este estudio, se han investigado los casos de prevención de la corrosión por armadura y se han sometido a oxidación el tipo de cemento y sus aditivos, como el sílice y el penitrón. Los resultados indican que el material de recubrimiento que consiste en penitrón de penitencia aumenta la resistencia a la compresión del cilindro. Pero el principal beneficio del penitrón es prevenir la penetración del concreto. Los mejores materiales se seleccionaron realizando experimentos y según el clima de Mahshahr, muestras de estructuras de hormigón armado con una relación agua-cemento de (p / c = 4%, p / c = 34%) y el lubricante de 6% - 2 % rango se construyó con un asentamiento fijo, y se tomó bajo pruebas de presión. Los resultados de las pruebas de corrosión demostraron que el uso de cemento que contiene 10% de sílice con una relación de agua-cemento de 34%, materiales FRP de armadura y penitrones es la mejor propuesta técnica y económica para reducir la corrosión en Mahshahr.

Palabras claves: relación hormigón, agua-cemento, grietas, corrosión, eflorescencia.

Resumo

Atualmente, a maioria das estruturas civis é construída em concreto, cujo uso aumenta diariamente. Devido a ignorar os princípios de construção (para a durabilidade do concreto), corrosão provoca custos substanciais para estruturas após um curto período de funcionamento que em alguns casos reconstruindo a estrutura é ainda mais difícil, em vez de renová-lo. Este problema é ainda mais crítico sobre a estrutura exposta à água do mar e a curta vida nas estruturas costeiras do sul confirmou-a. Além disso, com enormes recursos de petróleo e gás que estão sendo descobertos, ea construção de grandes instalações petroquímicas do Golfo Pérsico, levaram à necessidade de grandes projetos de construção e desenvolvimento na área. O clima e os minerais quentes e úmidos da região mostram sinais de deterioração, incluindo inúmeras rachaduras, corrosão, eflorescência e quebra de concreto. Estruturas de concreto armado no sul do país estão expostas a danos químicos ou eletroquímicos. O factor mais importante é devido ao fenómeno de corrosão de carbonatação ar (que ocorre como um resultado de dióxido de carbono no ar) e a penetração do cloreto (que passa através do betão e atinge o reforço). Os efeitos da corrosão, rachaduras e colapso do concreto e do sulfato de concreto diminuem significativamente a vida útil da estrutura. Este tipo de dano é maior na região da maré porque devido à umidade e secagem, o influxo de penetração de cloretos no concreto é intensificado e como resultado a taxa de corrosão aumenta. Diferentes métodos são usados para reduzir os danos das estruturas de concreto armado e o mais importante é melhorar a qualidade do concreto. Neste estudo, casos de prevenção de corrosão de armaduras foram investigados e o tipo de cimento e seus aditivos, como sílica e penitron, foram submetidos à oxidação. Os resultados indicam que o material de revestimento que consiste

em penitron penitron aumenta a resistência à compressão do cilindro. Mas o principal benefício do penitron é impedir a penetração do concreto. Os melhores materiais foram seleccionados através da realização de experiências e, dependendo do clima de Mahshahr, as amostras de betão armado com uma proporção de água-cimento (w / c = 4%, w / c = 34%) e do lubrificante 6% - 2 A faixa de% foi construída com um assentamento fixo e foi feita sob testes de pressão. Os resultados dos testes de corrosão demonstrou que a utilização de cimento contendo 10% de sílica com uma relação de água para cimento de 34%, de FRP materiais de armadura e penitrones é o melhor proposta técnica e económica para reduzir a corrosão em Mahshahr.

Palavras-chave: concreto, relação água-cimento, rachaduras, corrosão, eflorescência.

Introduction

Mahshahr in the Persian Gulf region is one of the most vulnerable areas for the penetration of chloride corrosion in concrete and its bars due to specific geographical conditions such as high temperature, humidity, and wind (Talib, Rasheeduzzafar & Al-Gahtani, 1986). In these areas, the influence of chloride, carbonation and corrosion phenomena have casued extensive damage in concrete. The combined presence of chlorine ions and sulfate in the region has created a unique situation; on the other hand the existence of important facilities of gas, oil and petrochemical industries in the region and the corrosion due to chloride and sulfate ions generated by the presence of water, soil and even the atmosphere cause great damage to the installation (Cabrera & Nwaubani, 1980; Pourbaix, 1974; Campbell, 1978; Ramazanianpoor & Malhotra, 1995).

Until the new marine structures were not common in the southern coastal areas and building structures with traditional materials were limited the climate of these regions were not as detriment. The development of the oil industry and the construction of new port facilities in coastal and southern coastal areas to meet the needs of the industry resulted in the use of steel pipes for of shore oil transfer and construction of jetties and concrete piles. The rust and corrosion of the steel items used in the buildings attracted attention of everyone to the climate of the area being detriment. The structures in south, which have high permeability and capillary pores cause ions move forward into the structure and thus put it in danger. Corrosion of reinforcement which is one of the factors damaging concrete structures in marine environment, concrete with low permeability, low detail design and structural deficiencies such as inadequate concrete cover quality issues cause salt and moisture penetration into the concrete (Regourd, 1975; Gonzalez, Algaba & Andrada, 1980; Standard, 1985; Mangat & Khatib, 1995). Focused salt and moisture in concrete reinforcement lead to corrosion causing significant damage to the structure. In recent years, a large number of concrete structures in different countries of the world, including Iran, have been injured of premature faiolure due to lack of concrete durability

(Neville & Brooks, 1987; Kumar Mehta, 1986; Gent, 1999; Jong, 2003; Teng, Chen & Smith, 2002; Lorenzis & Nanni, 2001) Damage caused by corrosion of concrete structures in the United States is estimated at US $ 10 billion annually, and this figure is similar in Japan, Canada and other major countries around the world. Corrosion of steel in concrete structures is the main cause of erosion and if we can protect bars in the concrete against corrosion the life of structures increases. The cost of rebar protection structure is negligible compared to the cost of construction and it can prevent a huge waste of resources (Zhao, 2000; Fukuyama & Sugano, 2000; Vassie, 1980). The purpose of this research was to mention some of the recent achievements in concrete as well as its future. In this regard we will get to the access development of high-strength and powerful concrete with low permeability with increased durability Geological studies indicate that due to the expansion of the desert in a non-permeable zone of fine grained sediments recharging the rocks by the Trojan plain and marginal is not possible due to distance.

Several geological layers observing the characteristics suggest that silty fine- grained alluvial layer on the surface is about 40 meters deep and it is among the non- permeable structures. Due to the low- Trojan and Aghajari compact formation and metamorphic rocks in the western plateau the possibility of groundwater in layers is also negated. According to available information, the level of

groundwater in Mahshahr and Bandar is about 3 meters deep. The salt concentration in this region is also very high and thus the structures are at risk of serious injury.

The Climate of Mahshahr

Generally, the sky is cloudless and warm in summer and mild to cool due to northwest winds. Rainfull is quite low and almost confined to the winter and sometimes spring months and there is almost no rainfall during summer months. Dust storms and salt water coastline can be seen and they sometimes cause visual field to be reduced to less than 1km. Weather factors are very important in terms of affecting the concrete.
The amount of rainfall in the area is limited and most of the rainfall is in the months of December and January and in summer there is almost no rainfall.

Bandar Mahshahr with a latitude of 30 degrees and 30 minutes, according to the information recorded in the diagram position of the Sun about 31 degrees north latitude with a difference of half a degree of latitude with Bandar Imam and has the same difference with the petrochemicals in the region. The angle of the sun at noon on the first day of January is at its lowest position during the year, 35 degrees and it is 85 degrees at noon of the first day of July, when the sun is at the highest position during the year. These angles cause the building to the south to create 4/1 and 14/0 deep shades to its height respectively.

Assessment of Damage Causes of Reinforced Concrete Structures in Mahshahr Petrochemicals

Fatigue and Detrition Causes of Concrete Structures

It is a process in which carbon dioxide CO2 is released from the atmosphere and enters the pores of the concrete, causing the concrete being alkaline. Carbonation reduces PH by 8 or 9 times. While the screen oxide does not have long- term sustainability in this case, the corrosion starts with enough oxygen and humidity. Carbon thrust in the concrete is a slow process and its yield is determined by the amount of CO2, which has penetrated the concrete.

Permeability

Permeability is the case of liquids and gas moving in concrete in a way it can leave a damaging effect on the concrete. Penetration depends on the porosity of the concrete and because it determines the quality of the concrete being saturated with water, the permeability of concrete in corrosive environments is an important effect on susceptibility. In addition, concrete reinforcement corrosion due to the weather is associated with the expansion of the volume of steel, zinc fittings, cracks, and concrete with degrade over time.

Causes of Reinforcement Corrosion
Ingress of Salts

Salt deposits as the result of evaporation or the water minerals and salts that are collected by the wind in the pores and cracks can bring great pressure to the buildings and this operation accelerated and intensifies corrosion of reinforcement in addition to rust which is due to the presence of salts. Alternate wetting and drying, can also increase the concentration of salts because water minerals leaves the salt after evaporation.

SPECIFICATION ERRORS

Improper application of standards and technical specifications in relation to the wrong choice of materials, procedures and practices can lead to concrete damages. For example, using European and American standards for the implementation of projects in the Persian Gulf, where weather and construction materials and skills differ from all these factors in Northern Europe and the US, causes the durability and reliability of concrete structures in this region to be decreased and the thus we will face very serious problems with the exploitation of structures.

CONSTRUCTION EFFORS

Hypothyrodism, and the mistakes that occur during the execution of projects may cause the injuries, such the phenomenon of honeycomb, water holes, determent, shrinkage cracks, voids additional or contaminated concrete arise and all of which can lead to serious problems. These defects and performance problems can be due to the degree of compaction, ouring systems, contaminated water contaminated sand and incorrect use of additives individually or as a group.

CHLORIDE ATTACK

The existence of free chloride in concrete can damage and destroy protective layer around the reinforcement. Chloride corrosion of reinforcement in concrete is an electrochemical action, according to its properties in this process provides the concentration of chloride ions required, anodic and cathodic areas, the presence of electrolyte and cathodic regions oxygen reaching the cells.
It is said that chloride corrosion occurs when the amount of chloride in concrete is more than 6,0 kg per cubic meter, but this amount depends on the quality of the concrete as well.

Smallpox corrosion of chloride can be regional and deep which occurs in presence of a very small anodic and a very broad cathodic surface and the corrosion is intense.

The features of chloride corrosion include:

a) When the chloride in the intermediate chemical compounds (action and reaction) is used, but at the end the chloride is not used.
b) When the simultaneous formation of hyerochloric acid reduce the PH degree of corroded areas. The existence of chloride can be due to the use of chloride additive and also the influence of the surrounding air.

It is assumend that amount of chloride ions penetrate follow the FICK's law. But in addition to the diffusion the chloride penetration is likely to occur due to capillary suction.

SULPHATE ATTACK

The concrete attacked by the sulphates has a white appearance. Usually, the damage begins with the edges and corners and continues with cracks. These sympotoms are due to sulfate attack resulted in the formation of calcium sulfate such as gypsum (GXPSUM) and calcium ettringite. Both products have a higher volume and the expansion and are hardened concrete pouring compared to the alternatives to chemicals.

Fire

There are three main factors that can increase concrete durability against fire:

a) Concrete's ability facing heat as well as sealing action without cracks, cast or resistance reduction.
b) Conductivity.
c) Heat capacity

It should be noted that the two opposite properties of expansion and shrinkage are responsible for concrete damage to heat. As pure cement's volume increase in the vicinity of high temperatures, the concrete has the tendency to shrink and shows contraction in the same conditions.

Frost Action

For wet concretes, frosting is a damaging factor. Because water's volume increases while frosting and generated damaging inner tensions which lead to cracking. Cracks that are due to alternative frosting and melting make the surface of the concrete sequin shaped and damage is more deep due to erosion therefore freezing and resulting damage depends on the degree of porosity and permeability of concrete and that this effect of the cracks.

De-icing Salts

If salts are used in order to melt the concrete's ice, it might lead to further damage. Because it is believed that the injuries caused by de-icing salts occur as a result of a physical act. Concentration of salts, the water with ability of freezing and the hydraulic pressure and members (OSMOTIC) play as important role in the scope and extent of the damage

ALKALI- AGGREGATE REACTION

In this part the "alkali - silica" and "alkaline – carbonates" interactions are investigated. The "alkali – silica" interaction include gel produced from reaction between potassium hydroxide and silica in aggregate. The "alkaline – carbonates" interaction occurs between the alkali in the cement and a certain amount of limestone (DOLOMITIC) when placed in wet conditions. The interaction begins with the attack of silica minerals to alkali hydroxides (K2O or Na2O) derived from cement alkalis. The created silica – alkaline gel using capillary or osmotic properties absorbs water and therefore tendency to increase the size emerges. Because the gel is limited by the cement paste, internal pressure is built leads to expansion, crack and rupture of cement paste (outside fading and peeling) and

widespread cracking of concrete. Other factors influencing the development of aggregate – alkaline reaction include porous aggregates, the amount of alkali in the cement, access to water penetration and cement paste.

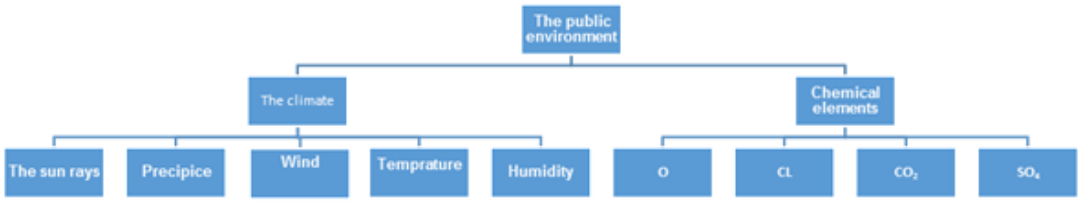

Figure 1 Classification of Environmental Conditions

Persian Gulf Environment Conditions

The problems of concrete construction are due to two important factors in the Persian Gulf.

a) Concreting in hot weather
b) The oxistence of damaging elements

These two factors result in porosity and damage in concrete structures (some behavioral changes and decreased resistance).

The Weather Effect on Concrete Construction

When the concrete temperature rises following signs occur:

a) The amount of water required to achieve a specific application increases. In other words, water- cement ratio will be further.
b) The applicability of fresh concrete quickly reduces and the density of concrete is inappropriate. To compensate this problem an increase in water- cement ratio is required.

In addition, the climate condition affects the following factors:

1. The possibility of cracks in the concrete surface in terms of shrinkage due to drying which increases in regions with low humidity. The temperature degree of the concrete and surrounding area, relative humidity and wind pace are among affecting factors of this phenomena. In case the rate exceeds from one kilogram per square meter per hour actions are necessary to be taken to prevent cracking. This issue is always present in dry and hot regions.
2. The development and distribution of temperature due to the water absorption of cement which results in temperature degree increment of new concretes and thus the possibility of cracking increases (due to the concrete drying).
3. Spongy layer formed on surfaces as a result of the rapid evaporation of water.

Impactful Factors in the Prevention of Damage to Concrete
Concrete Quality

The quality of concrete has direct effect on its durability. Concrete durability is one of its most important properties because it is necessary that it endures the condition for which it is designed. External factors from the environment or the internal ones in the concrete can cause durability decrease. These factors can be divided to four physical, chemical, mechanical and biological classifications. Physical factors are result of frosting and differences between the thermal properties of aggregates and cement paste while mechanical factors are essentially in relation to triturating.
The attack of sulphates, acids, sea water electrochemical corrosion of reinforcements by chlorides are among the chemical factors.

Concrete Cover on the Reinforcement
The issue of concrete cover corrosion on the reinforcement is of great importance. Of cource in specific places and cases, further covering using protective material is recommended but generally a proper concrete cover can greatly prevent or delay the attack of chlorides and sulphates. For example if the cover thickness is 5

cm it can protect the reinforcement five times more than a cover with 2 cm thickness.

Porosity

Porosity depends on the cement – water ratio and hydration degree. The W/ C ratio is the main factor affecting the porosity.
Porosity also has a great effect on pressure resistance. Meaning higher porosity reduces pressure resistance.
The amount of prosity has an impact on electrical resistance of the concrete with a reverso ratio, meaning it decreases with electrical resistance increments.

Permeability

Permeability is a micro – structural property of concrete which shows the building material capability for passage of fluids with a viscosity rate of the specified pressure gradient. Permeability is directly associated with the microstructure of concrete quality. Also, since in most cases the attacker fluid enters from the outside into the concrete, permeability of concrete facilities or fluid login into the concrete environment. This property is concerned in connection with the sealing of water retaining structures and also in relation to chemical weapons.

It is necessary to note that in terms of durability and quality of concrete, achieving lowest permability possible is quite important. The lower the water – cement ration, the faster the permeability decrement.
Also, permeability is important because it can control the intensity of the attacker's penetration whether in the primary or developed corrosion levels.

Concrete Type

Table (1) the effect of concrete type on chloride penetration speed in the concrete in regions exposed to sea at 30 $^{\circ}C$

Concrete type	Description	After 3 Months	After 6 Months	After 9 Months	After 12 Months	After 15 Months
Slag cement	Chlorine penetration	**8** mm	**13** mm	**15** mm	**20** mm	mm **20-30**
Middle East Sand	Corrosivity	-	-	-	-	-
Anti-Cement	Chlorine penetration	Perfect	Perfect	Perfect	Perfect	Perfect
Middle East Sand	Corrosivity	Salt spots	Traces of corrosion	Corrosion	-	-

Surface coatings for concrete protection

Table 2: classification system protection

Material	System type
Acrylic Epoxy resin Polyurethanc	Coatings and sealant
Silane Silozane	Penetrating
Silicate	Blocking the pores
Polymer cement martar with or without polymer	Coated surface

Additives

In general additional materials can be divided into three categories:

a) Additional chemical materials used to reduce water consumption, smoothing ability and control the time
b) Additional trapped air material used for the smoothing ability to avoid disturbing the size and increase the durability of concrete during pouring
c) Additional mineral material used to control hydration temperature and prevent chemical interactions of alkaline the concrete and aggregates.

Conclusion

Based on the results of the experimants, the following was concluded:

1. The compressive strength of concrete cylinders coated with penitron is a little more than cylinders without coverage. The increase is approximately 6% compared to concrete without cover. However, the main advantage of penitron is waterproofing and avoiding the permeability of concrete rather increasing compressive strength.

2. It was revealed the depth of penitron penetration into the concrete components is as follows:
0 to 50 mm – significant
5 to 10 mm – average
10 to 20 mm – some
25 to 50 mm – low
50 mm and up – por

It must be noter that this amount is resulted from the final 14 day period of concrete's life. The longer the concrete's life, the higher the amount and the probability of penetration.

Microspopic examination revealed the fact that the components of penitron penetrate intoe the concrete surface and lead to the growth of crystal white material. It seems that the crystalline materials are in fact products of penitron components with hydration calcium – silicate gel in the concrete particles.
3. Water pentration in concrete with of penitron cover is significantly lower compared to the concrete without a penitron cover. This indicates that performing penitron significantly modifies the concrete's waterproof properties.

4. The amount of chloride in penitron water is very low and appropriate to concrete's amount. The results of this experiment indicate that the beneficial effect of penitron is irrelevant to chlorides.

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